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14. ABSTRACT
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3D Mapping, 3D Synthetic Environment, Terrain Modeling, Wavelet Transform

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Using wavelet transforms in 3d mapping

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ABSTRACT

The Naval Research Laboratory's Digital Mapping, Charting and Geodesy Analysis Program is investigating the application of wavelet technology to terrain approximation in 3D mapping. The wavelet transform allows us to obtain the frequency content of gridded elevation data while retaining the spatial context. We use a 2D discrete wavelet transform (DWT) to reduce Digital Terrain Elevation Data to low and high frequency components. The low frequency components represent widespread fluctuations in terrain and over large areas give a very close approximation to the original data set. Each application of a wavelet transform gives us a 75% reduction in the amount of data that must be displayed. A level 2, 2D DWT allows us to represent large amounts of terrain data with only 6.25% of the original data. A reverse transform on the reduced data set makes possible the restoration of any level up to the original data with only minor loss, making the application suitable for multi-resolution systems. This application is also ideal for time-critical applications. Processing 1,073,179 DTED elevations down to 67,304 takes approximately one-half second. Optimized triangulated irregular network algorithms are reported to require over 45 seconds for a similar sized data set. We describe the application of wavelet technology to Internet-based 3D mapping. In addition to custom 2D maps that may consist of vector, raster and gridded data, users may generate 3D maps by area-of-interest.

Keywords: 3D Mapping, 3D Synthetic Environment, Terrain Modeling, Wavelet Transform

1. INTRODUCTION

Although mapping has existed for millennia, the use of maps has evolved from a basic paper chart to digital thanks to the ever-expanding use of computers. The Digital Mapping, Charting and Geodesy Analysis Program (DMAP) at the Naval Research Laboratory has been actively involved in researching digital mapping databases since 1994. Our work began with a successful prototype of the first object-oriented application using the National Imagery and Mapping Agency's (NIMA) Digital Nautical Chart. Since then, we have included a variety of products from NIMA and others. Our focus started on the Geospatial Information Database (GIDB), an object-oriented database, from which we provide user-customizable digital maps over the Internet. Our work has more recently expanded to a system that gives users near-seamless access to data from the GIDB and also from a variety of other geospatial and temporal databases distributed across the Internet. This allows users, for example, to incorporate current temporal weather forecast data with traditional geospatial data in a mapping context.

We are evaluating the use of wavelet technology as part of our effort to provide Internet-based 3D mapping. Wavelet transforms have been successfully used in many fields to obtain significant data compression without loss of meaningful content. They are also fast, making them feasible for use in time-critical applications. We are interested in using wavelets to compress digital terrain elevation data in order to make more efficient use of bandwidth and to improve application performance. Our goal is to achieve substantial data compression while obtaining a reasonable approximation to the original data.

We describe our application of wavelet technology to Internet-based 3D mapping. In addition to customized 2D maps, users may generate 3D maps by area-of-interest. These 3D maps consist of wavelet-processed terrain elevations overlaid with the customized 2D map.

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2. OVERVIEW OF WAVELETS AND THEIR USES

What is known as the discrete wavelet transform can best be summarized by the following quote. "Wavelets are mathematical functions that decompose data into different frequency components and then study each component with a resolution matched to its scale. They have advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes. Wavelets were developed independently in the fields of mathematics, quantum physics, electrical engineering, and seismic geology. Interchanges between these fields during approximately the last ten years have led to many new wavelet applications such as image compression, turbulence, human vision, radar, and earthquake prediction."[1] Wavelet based methods present a different way of processing data. Terrain height fields or other signals can be viewed and manipulated on multiple scales. They allow large data sets to be compressed, while important features are retained. This has obvious advantages for data transmission and display.

3. TERRAIN MODELING TECHNIQUES

3.1 Grids

Terrain modeling typically involves use of single or multiple resolution grids or Triangulated Irregular Networks (TINs), according to the needs of the user, to store terrain elevation data. The grid model superimposes a rectangular grid on the *xy* plane. The data points at the intersection of the grid intervals give the elevation, and the rectangular patches of the grid can be further subdivided. This model can be adapted to a multi-resolution grid or hierarchical mesh which displays a fine grid in areas near the viewer and coarser grids with less detail in more distant areas.[2] Gridded terrain elevation models are considered easy to use. The data points that coincide with the regular grid intervals are used or interpolated in the event no data points coincide with the grid intervals. A finer mesh is generally considered necessary in order to achieve precision with rough terrain such as mountainous areas.[2]

Digital Terrain Elevation Data (DTED) is a well-known gridded product from NIMA. DTED data is readily available for most of the world. Elevation spacings vary and include 100 meter, 30 meter and higher resolutions. When it is necessary to reduce the volume of DTED or other gridded terrain elevation data for production of a terrain model, the original data is typically down sampled using distance, uniform sample or some other metric.[3]

3.2 Triangulations

The TIN, unlike the grid, approximates the surface by means of a network of planar, non-overlapping and irregularly shaped triangular facets, with the vertices of each triangle located at the data elevation points.[4] A TIN can approximate any surface at any level of accuracy with a minimal number of polygons.[5] A TIN is constructed by the extraction of the fewest number of elevation points that contain as much information about the terrain elevation as possible. These points become the vertices of the TIN triangles. This decreases storage requirements and improves the approximation of the terrain surface.

Extracted elevation points can be triangulated in many ways to construct a TIN. The Delaunay triangulation, however, is considered to produce the most accurate representation of the terrain. A Delaunay triangulation is one in which no circumcircle of any triangle contains another data point in its interior. This restriction produces triangles that are as equiangular (angles close to 60 degrees) as possible. This avoids thin elongated triangles that fail to preserve local variations in elevation and that cause problems with precision and interpolation.[4]

3.3 Constrained triangulations

A constrained Delaunay triangulation is one in which line segments have been used in the triangulation process to further enhance surface representation. These line segments become mandatory TIN edges.[6] The line segments can be part of a significant surface feature such as a ridgeline, transportation network or shoreline. When these line segments form the boundary of an area feature, for example, all triangles composing the area feature are guaranteed to have the same constant slope, eliminating slight inconsistencies in the elevation. This can be useful when integrating a 3D building model onto a rough surface.

3.4 Hierarchical triangulations

Hierarchical TINs are used to represent terrain at various levels of detail (LODs). Each node in the hierarchy, except for the root, is a TIN surface approximation that is a refinement of a parent node. More triangles and therefore more detail are contained at deeper levels of the hierarchy. An appropriate subset of the TIN data is selected for display according to a particular eye point position or distance selected by the user. The hierarchy allows the displayed scene to smoothly shift or morph to different LODs as required by the user. The production of TINs for LODs has often focused on the techniques and difficulties of triangle decomposition.[7]

4. WAVELET TRANSFORM OF TERRAIN DATA

Our application domain does not require the rigors of a constrained Delaunay triangulation since we are producing 3D maps for situational awareness instead of placing 3D objects onto an irregular surface. While the wavelet transform will not allow the imposition of constrained edges, it should identify and maintain significant features such as ridgelines and valleys. The wavelet transform affords the simplicity of use offered by grids with some of the data reduction promised by TINs. The reverse transform offers the ability to transmit highly compressed data over the Internet, which can then be uncompressed on demand to object representations of the terrain at various LODs.

4.1 Methodology

We use a 2D discrete wavelet transform (DWT) to reduce DTED to low and high frequency components. The low frequency components represent widespread fluctuations in terrain. Over large areas these give a close approximation significant terrain changes. Each application of a wavelet transform gives a 75% reduction in the amount of data that must be displayed. A level 2, 2D DWT, for example, allows us to represent large amounts of terrain data with only 6.25% of the original data, a 16 to 1 compression factor. A reverse transform on the reduced data set makes possible the restoration of any level up to the original data with small loss, making the application suitable for multi-resolution systems. This application is also ideal for time-critical applications. Processing 1,073,179 DTED elevations down to 67,304 is timed at approximately one-half second. Optimized triangulated irregular network algorithms are reported to require over 45 seconds to select 50,000 elevations from a universe of one million.[8]

Much like Fourier transforms use sines and cosines, DWTs use what are called basis functions to characterize data. For this work we have chosen basis from the Daubechies family of wavelets.[9] The method employed for this process works on a regular 2D grid of terrain elevations using a 2D DWT. The wavelet is applied to the grid producing four "sub-images," each containing one-fourth the points as the original. The four sub-images are an average, a vertical detail, a horizontal detail and a diagonal detail. The average retains significant large-scale details of terrain variance and is retained for display as 3D terrain points.

4.2 Error measure

In this section our 2D DWT is compared to two alternative methods of compression, uniform down sampling and averaging. For further comparison, two wavelet transforms are employed: one with basis size of 4 and one with basis size of 8. Basis size refers to the number of elevation data points used to compute each compressed point. The test data consists of a 256 by 256 terrain elevation grid. First and second level transformations were performed using each of the four methods. A first level transformation compresses the data down to 25% of the original data points, and a second level transformation compresses down to 6.25% of the original. Inverse transforms were then employed, and the resulting data was compared to the original. The results are depicted in Figure 1. This chart shows the average difference between the original and calculated data points for each of the four methods. Simple down sampling resulted in deviations of 0.61% and 1.48% for first and second level transforms respectively. The averaging method resulted in deviations of 0.49% and 0.90%. Wavelet transforms yielded deviations of 0.29% and 0.53% with a basis size of 4 and 0.26% and 0.49% with a basis size of 8.

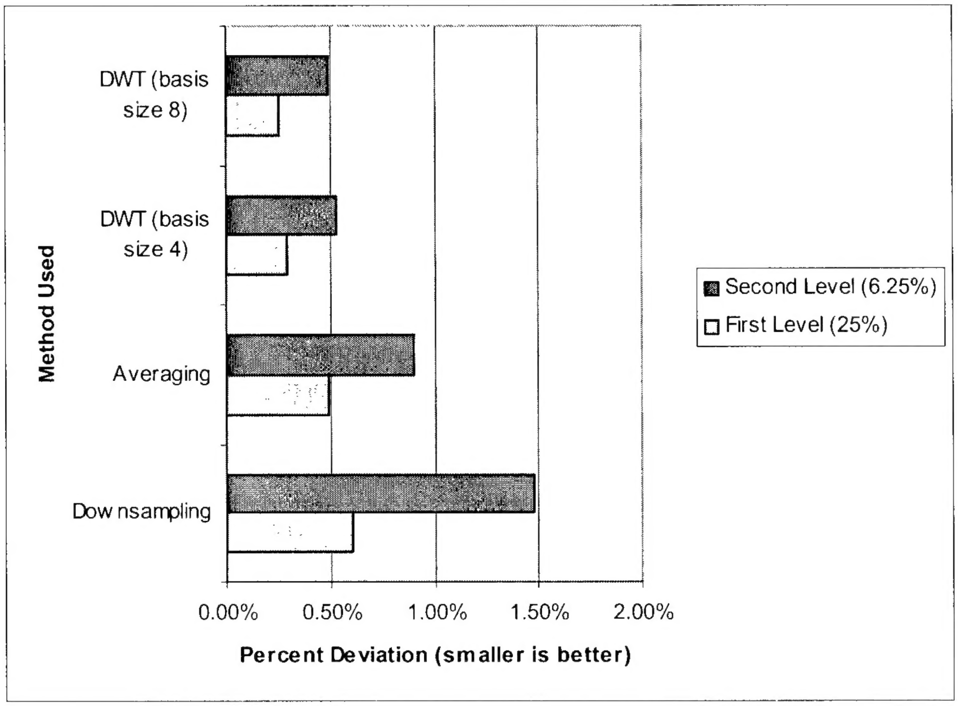

Figure 1: Comparison of the Discrete Wavelet Transform to Uniform Down-sampling and Averaging.

These results suggest the usefulness of wavelets in two situations. One is the multi-resolution system in which data is compressed by a DWT and reverse transforms are applied to restore each of several levels. The other is the use of wavelets to compress gridded elevation data for transmission or storage with a reverse transform applied to restore the original. In particular, consider a dataset of elevation points with average elevation of 1000 meters. Using the wavelet method one can achieve a fast compression of 16:1 and then uncompress for with values that are on average, as suggested by these results, within 5 meters of the original.

While this analysis consisted of a comparison of the original data against the inverted DWT processed data, similar results were obtained through a comparison of compressed points with the corresponding original points. In that case the DWT processed elevations were within approximately 0.7% of the original data. Although down sampling results in no difference between the retained elevations and the original data, down sampling may lose important large-scale features within the down sampled data whereas the DWT preserves these features.

5. PROTOTYPED APPLICATION

We have prototyped the use of the wavelet transform in our Geospatial Information Database (GIDB) system. The overall system consists of a database, a Java applet user interface and a communications portal. The GIDB database is a spatio-temporal database that is currently managed by an open-source object-oriented database management system, Ozone. Since Ozone is open-source, we have been able to modify the source code where necessary to customize to our particular needs and, more importantly, we have eliminated costly commercial database licensing fees on deployment. The system portal connects users to the GIDB database and other databases distributed on the Internet, and it assembles heterogeneous data in a common geo-referenced presentation to the user. Currently interfaced data sources include Fleet Numerical Meteorology and Oceanography Center (FNMOC), U.S. Geological Survey (USGS), Digital Earth/NASA, and the Geography Network/ESRI, among others. A significant FNMOC product, for example, is the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), which consists of gridded atmospheric and ocean prediction data. The atmospheric components of COAMPS are used operationally by the U.S. Navy for short-term

numerical weather prediction for various regions around the world. The GIDB system provides a convenient means for users to obtain COAMPS data and incorporate it with vector and raster data in map form.

Users of our system may build custom 2D maps for virtually any area of interest in the world and then generate the corresponding 3D map on demand. The 3D map provides the functionality of a 3D synthetic environment by allowing the user to fly-through, walk-through, obtain positional information and orient the view as desired. The 3D map consists of wavelet-processed terrain elevations overlaid with the user's customized 2D map.

Figure 2 below gives an example of the user interface to the GIDB system. A map has been configured over Southern California covering an area of approximately 1-degree square. Data shown on the map includes a CADRG backdrop overlaid with National Imagery and Mapping Agency vector data. The map is a 'live' map in the sense that the vector data can be queried for its attributes. In addition to attribute query, the interface gives the user the ability to pan and zoom, to change backdrops, to add temporal data such as weather forecasts, to change the color and line thickness of vector features, etc. Figure 3, for example, shows the same area with the addition of forecasted wind data.

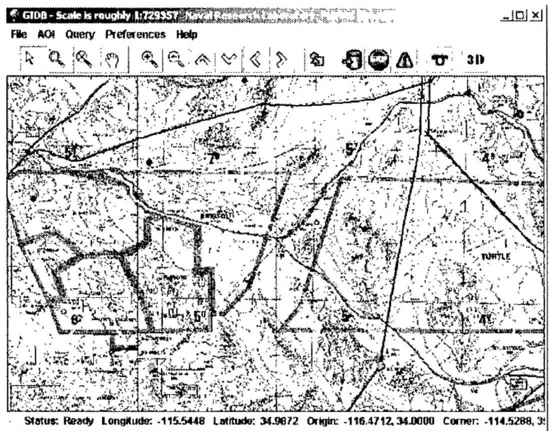

Figure 2: The GIDB User Interface Combining Raster and Vector Data.

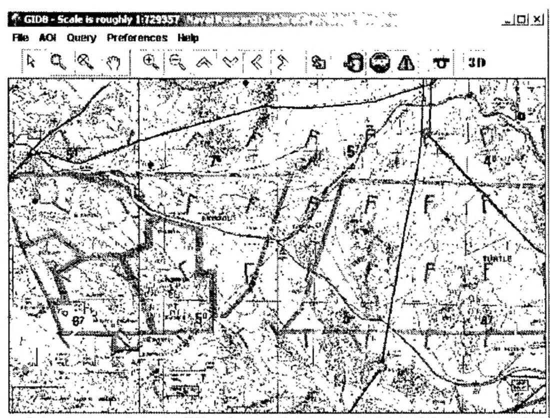

Figure 3: The GIDB User Interface Combining Raster, Vector Data and Weather Data (Wind Barbs).

The GIDB interface allows the user to obtain a 3D map on demand, as shown in Figures 4 and 5. The server is queried for the elevation data and the wavelet transform is applied. The newly compressed data is then transmitted back to the client for display. The 3D application uses Java3D. The user is able to fly-through and to evaluate the topography from

any vantage point. Specific functions on the 3D map allow the user to jump to cardinal compass points, vary navigation speed and exaggerate the elevations. The terrain can also be rendered as a mesh if desired.

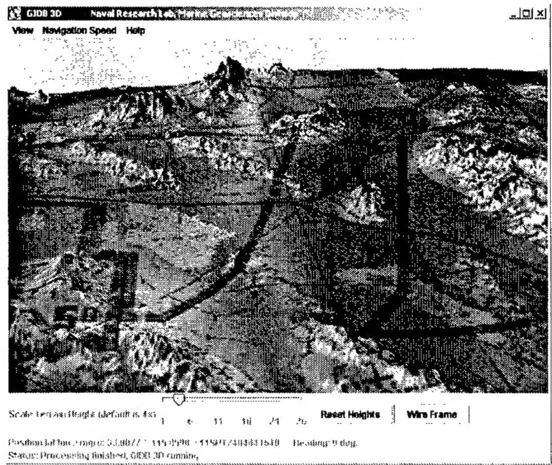

Figure 4: A GIDB 3D Map for the Area Shown in Figure 2.

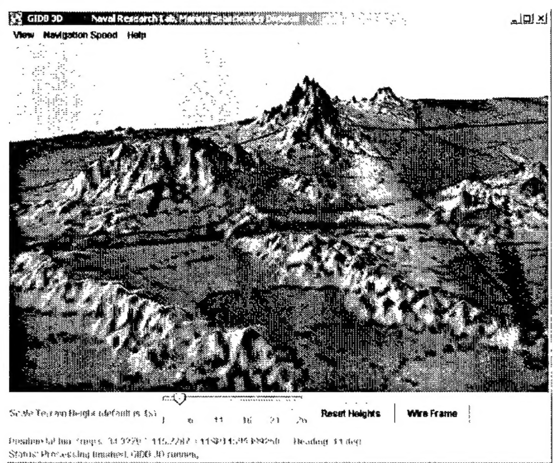

Figure 5: An Alternate View of the 3D Map Shown in Figure 4.

Our interface allows the user to choose the extent to which the terrain data is compressed as shown in Figures 6, 7 and 8. Figure 6 uses the full dataset. Major features are shown along with detail. Figure 7 shows the scene with a 4 to 1 compression or 25% of the original data. This rendering shows all of the major features and some of the details shown in Figure 6. Figure 8 provides 16 to 1 compression or renders the scene with 6.25% of the original data. The major features of the terrain are still defined. Some detail is present but not to the extent present in Figures 6 and 7. The ability to provide a 16 to 1 compression ration allows us to create a 3D display of large areas that offers reasonable performance on a wide range of personal computers.

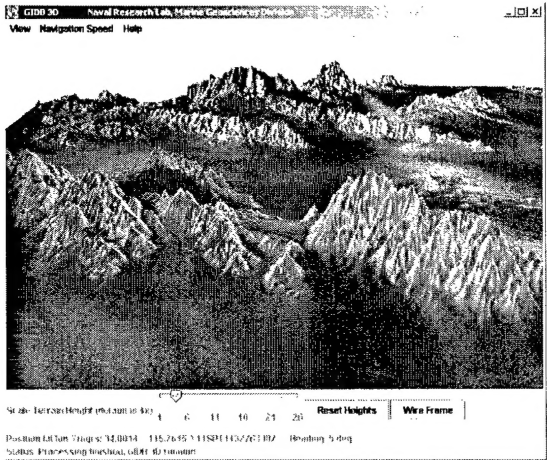

Figure 6: Results Showing No Data Compression.

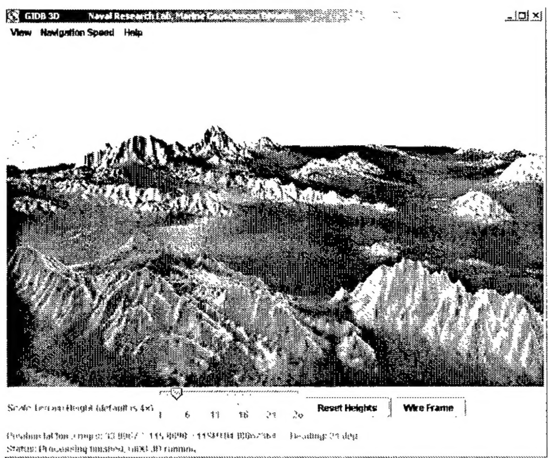

Figure 7: Results Showing 4 to 1 Data Compression.

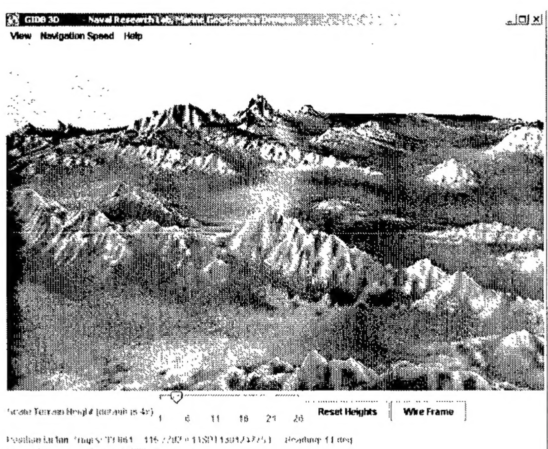

Figure 8: Results Showing 16 to 1 Data Compression.

6. CONCLUSIONS

We have found the use of DWTs that we have described to be basically satisfactory in our preliminary evaluations. Our preliminary results suggest that for terrain visualization DWTs may provide a suitable alternative to other compression methods for gridded elevation data such as uniform down sampling and averaging. We are continuing with more extensive testing and evaluation. Further investigation is warranted into the suitability of DWTs where a small data loss can be tolerated such as multi-resolution visualization systems and where storage and bandwidth capacities are at issue. In the latter case, a DWT would be used to compress gridded data for storage or network transmission, with a reverse transform applied to restore on demand. We have shown the prototyped use of DWTs in our GIDB system that allows a user to obtain a 3D map of an area-of-interest over the Internet on demand. Results were shown comparing 3D scenes with no data compression to ones with 4 to 1 and 16 to 1 compression ratios. Higher compression ratios naturally improved 3D performance and decreased network transmission times.

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